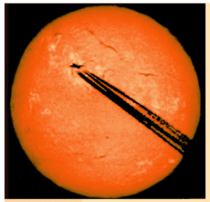


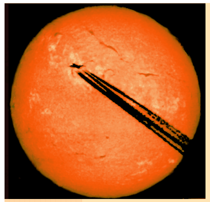
Effect of Cosmic Rays on Aircraft Crew

R.D. Bentley

Mullard Space Science Laboratory

University College London

KITE Club Healthcare SIG, 14 February 2006



Overview

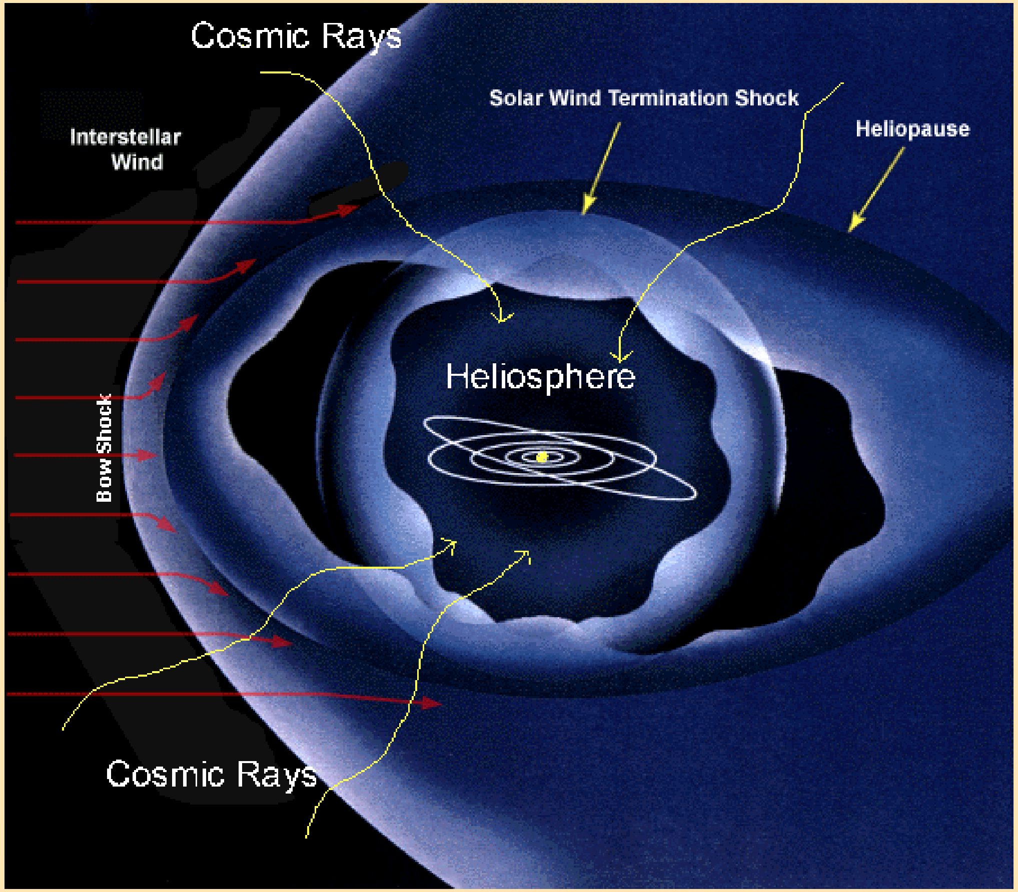
- Look at origin of cosmic radiation and how it varies at aircraft altitudes
- Describe the PIPSS project undertaken to measure the cosmic radiation and look for the influence of solar activity
- Legislation and how airlines comply
- Brief overview SOARS project
- Epidemiology and risks

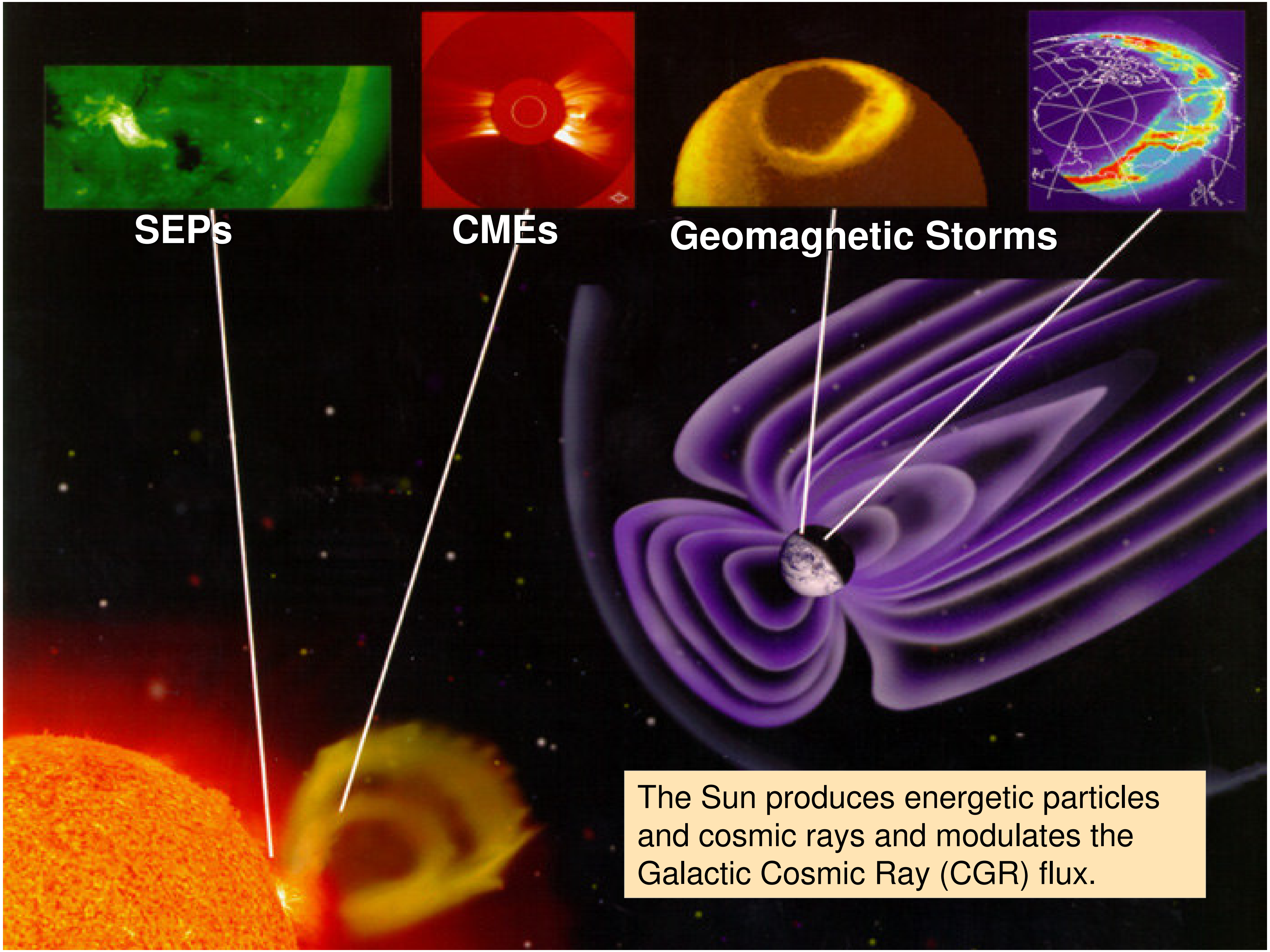
Based on work from PIPSS project to monitor cosmic radiation on aircraft and from an ESA Space Weather Pilot Project, SOARS, that is investigating the effects of space weather on the aviation industry.

PPARC SWENET

Sources of Cosmic Radiation

- The cosmic radiation incident on the Earth has two sources: Galactic Cosmic Radiation (GCR) and the Sun.
- GCRs originates from highly energetic astrophysical processes such as supernovae.
- The cosmic radiation from the Sun is typically less energetic and originates from solar flares and coronal mass ejections (CMEs).

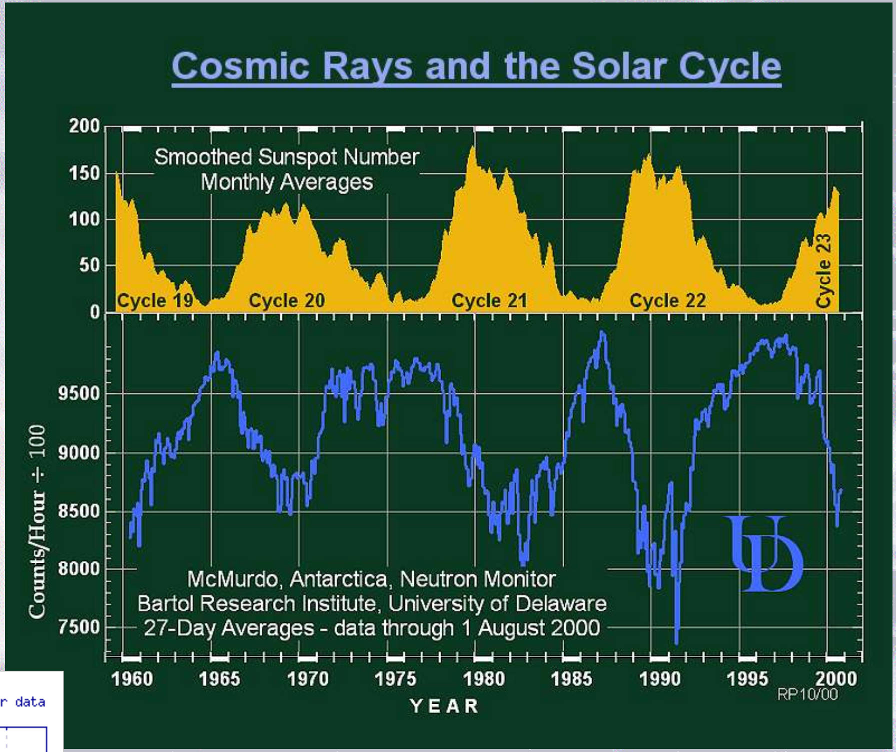


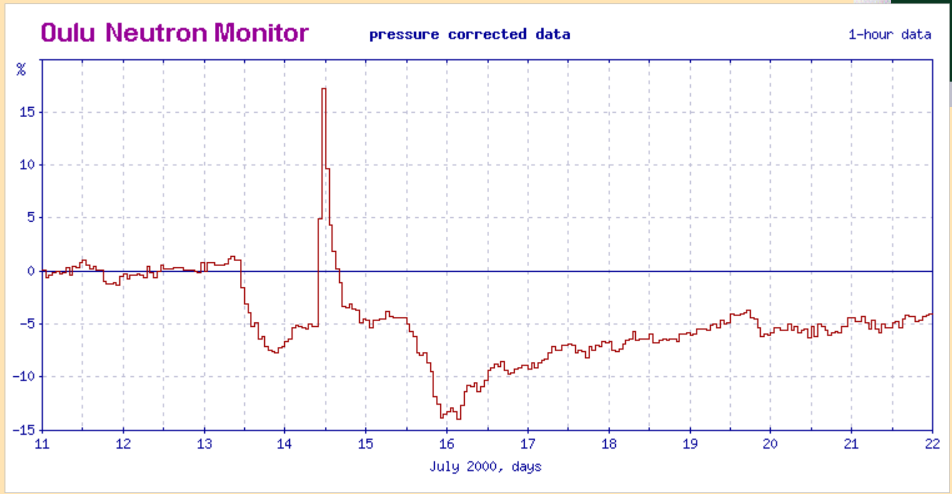

SEPs
CMEs
Geomagnetic Storms
The Sun produces energetic particles and cosmic rays and modulates the Galactic Cosmic Ray (CGR) flux.

GCR flux is modified by solar activity

The background cosmic rays flux is most intense at solar minimum when the Sun's influence on the heliosphere is at its weakest.

The flux is thus in anti-phase to the solar cycle.





The material carried in a coronal mass ejection (CME) can mask the galactic cosmic ray flux for many days – a Forbush Decrease

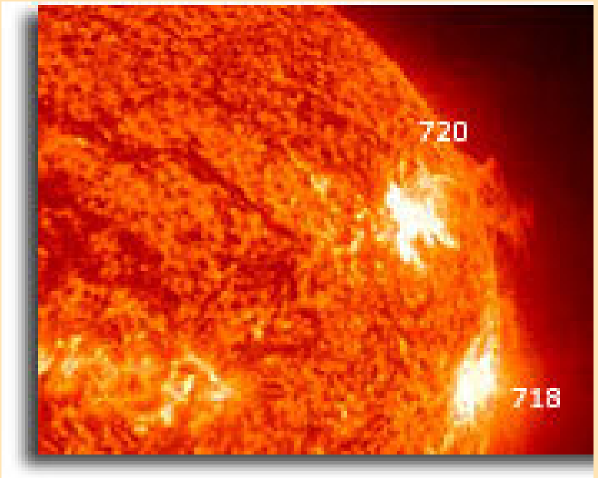
Space weather Operational Airline Risks Service (SOARS)

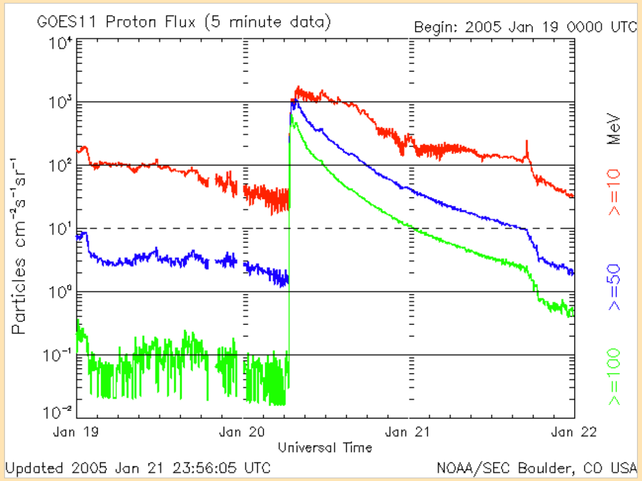
Radiation Storms…

Space weather Operational Airline Risks Service (SOARS)

Radiation storms can quickly follow the onset of a large solar flare. Highest energy protons (>100 MeV) travel fastest (up to a third the speed of light!).

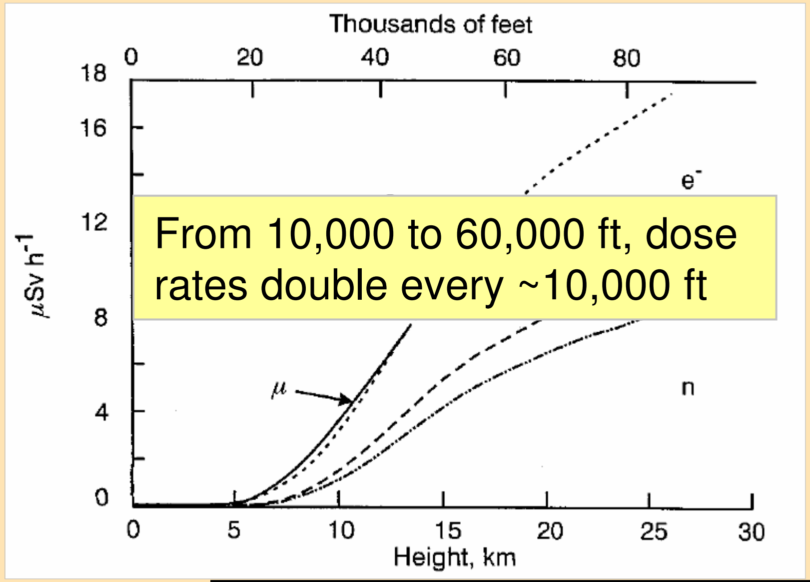
As of May 2005, there had been 85 (>10 MeV) radiation storms during the current solar cycle.



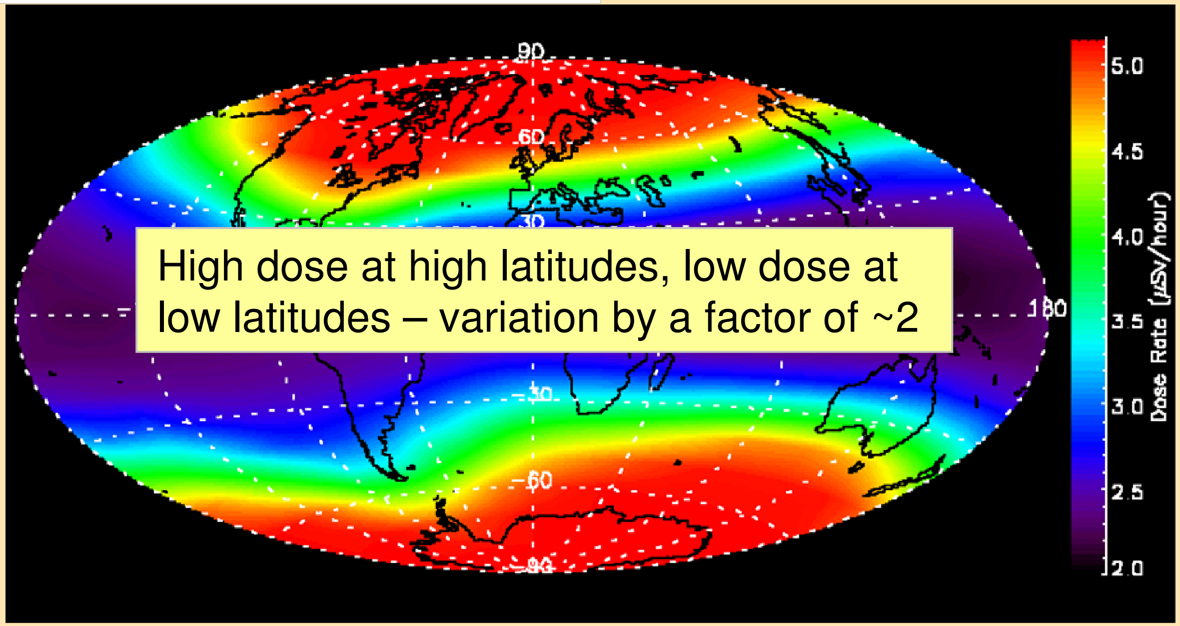


Jan 2005: X7 flare began at 20/0636 UT and peaked at 20/0701 UT. The Intense >100 MeV radiation storm peaked at 20/0710 UT. This storm was short-lived but did exceed the FAA Solar Radiation Alert at Flight Altitudes for about 1.5 hours.

Variation in Dose Rate



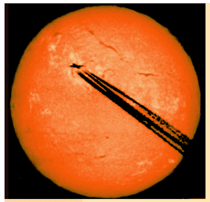
- The galactic cosmic ray background is modulated by the solar cycle and by coronal mass ejections, etc.
- Intense solar flares can add to the dose rate for short intervals
- The Earth's magnetic field shields us and the atmosphere provides a further barrier.
- As a consequence, the dose rate is dependant on altitude and location



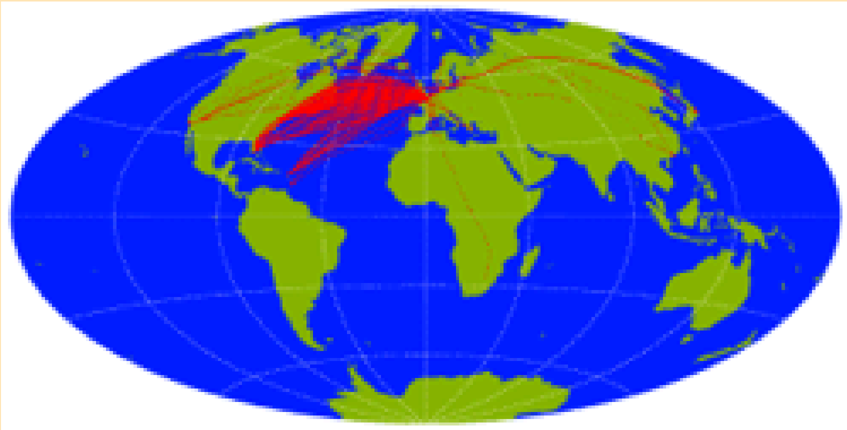
PIPSS Study

The Hawke TEPCs were carried in the overhead lockers and had batteries and flash memory cards that would allow them to take data for 3-4 weeks.

- This objective of the PIPSS study was to use of in-fight measurements, together with observations made by solar and space plasma satellites supported under the PPARC programme, to determine the influence of solar events on the radiation experienced at aircraft altitudes.
- In-flight measurements were made using Tissue Equivalent Proportional Counters (TEPCs) that were flown with Virgin Atlantic Airways.
- The data were analyzed to validate the current radiation dose models.

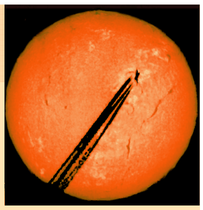


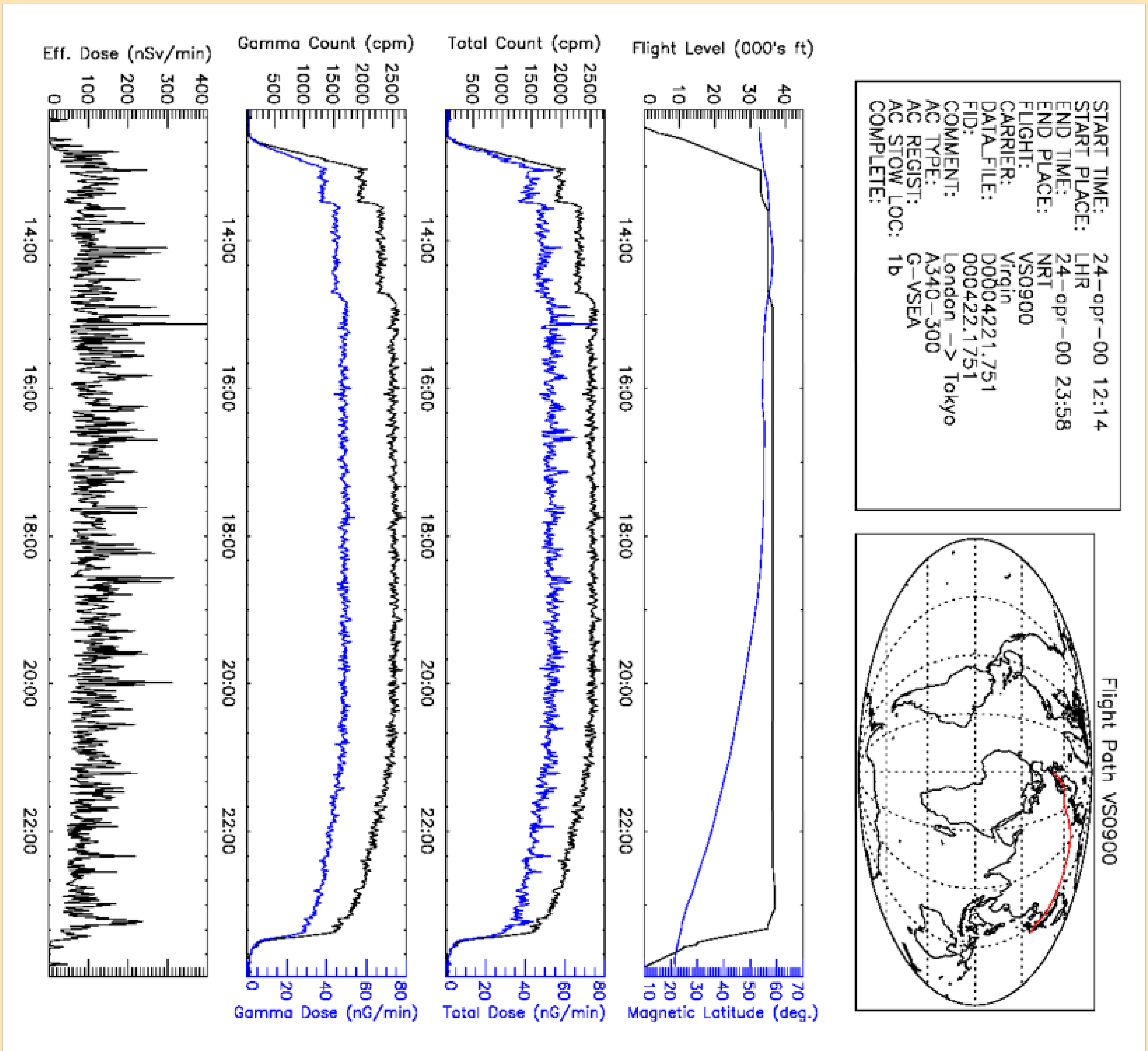
The observing campaign



- The TEPCs were flown on more than a 1000 flights in the northern hemisphere by Virgin Atlantic Airways
- Also flown on over 100 flights in the southern hemisphere by Air New Zealand
- Information about the flight profile had to be associated with the TEPC data post flight
  - Initially by hand
  - Later using engineering logs
- Light-curves from GOES used to identify solar activity

Space weather Operational Airline Risks Service (SOARS)

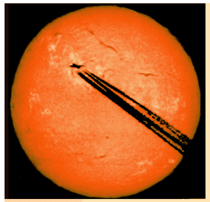




Typical doses

Route	No. of Flights	Mean Route Dose (µSv)	Std Dev (µSv)
London → Tokyo	4	52.5	3.7
Tokyo → London	3	59.3	2.7
London → Los Angeles	3	51.5	2.7
Los Angeles → London	2	47.9	1.5
London → San Francisco	2	46.8	1.4
San Francisco → London	2	38.0	4.5
London → Shanghai	2	43.4	3.3
Shanghai → London	1	56.8	-
London → Hong Kong	1	42.9	-
Hong Kong → London	1	55.0	-
London → Orlando	2	36.6	1.0
Orlando → London	2	28.9	1.3
London → New York	3	33.8	2.3
New York → London	2	29.8	1.2
London → Miami	2	30.8	4.7
Miami → London	1	27.7	-
London → Boston	6	30.7	3.1
Boston → London	4	25.9	3.2
London → Johannesburg	6	25.6	1.5
Johannesburg → London	5	25.0	3.1
London → Athens	4	11.4	0.9
Athens → London	4	13.0	0.6

The exposure on a trans-atlantic flight is roughly equivalent to a chest X-ray, but the quality of the radiation is different – CR mainly high LET neutrons



Legislation

- Since May 2000, European airlines have been required to assess the radiation dose experience by their crewmembers.
- CEC Directive 96/29/Euratom, article 42, requires airlines to assess the maximum annual dose that crewmembers will be exposed to if it is expected to exceed 1 mSV per annum.
  - Directive in response to recommendations of International Commission on Radiological Protection (ICRP) in 1990.
  - Implemented at the national level – led to variations across countries
- If the dose is liable to exceed 6 mSv per annum, monitoring of the dose received by individuals must be carried out.
  - Roster should be modified to try to avoid exceeding 6 mSv
  - For pregnant aircrew, article 10 applies: Once the pregnancy is declared to the operator, the dose should not exceed 1 mSv in the remainder of the pregnancy (ALARA).
- Dose assessment is commonly carried out using predictive computer codes – CARI, Sievert, EPCARD, etc.
  - These give reasonable approximations when solar activity is low!

Note: The radiation has a much higher component of high-LET radiation in aircrew (and astronaut) exposures, as compared with nuclear workers where 93% of exposures are from low-LET radiation.

(mSv)

Flight	Flight Date Code	Flight Route Code	TEPC H*(10)	TEPC E*	CARI-6 Feb-00 E	CARI 6M E	SIE-VERT E	EPCARD E	EPCARD H*(10)	EPCARD Ratio E/H	TEPC(E) /CARI 02/00	TEPC(H)/ EPCARD (H)	TEPC(E)/ SIEVERT	TEPC(E) /CARI6M
Lon-S/H	17180100	LS1	45.7	53.9	45.2	45.1	50.7	54.89	46.54	1.179	1.192	0.982	1.063	1.195
Lon-S/H	19200200	LS2	41.1	48.2	42.4	41.9	49.9	51.32	43.79	1.172	1.136	0.939	0.965	1.150
											1.164	0.960	1.014	1.172
Lon-JFK	18190100												1.206	1.200
Lon-JFK	27280300												1.107	1.210
JFK-Lon	28280300												1.102	1.209
Lon-JFK	17180400												1.163	1.259
JFK-Lon	18180400												1.106	1.269
Lon-JFK	17180700												0.986	1.090
													1.112	1.206
Lon-LA	29010300												1.076	1.282
Lon-LA	26270300												1.006	1.242
Lon-LA	16170400												1.094	1.290
LA-Lon	17170400												1.063	1.206
Lon-LA	16170700												0.923	1.103
LA-Lon	17170700												0.962	1.107
													1.021	1.205
Lon-JNB	23240300												0.950	1.027
JNB-Lon	24250300												0.876	1.035
Lon-JNB	02030400												1.027	1.047
JNB-Lon	03040400												0.855	1.048
Lon-JNB	05060400												1.002	1.036
JNB-Lon	06070400												1.025	0.977
JNB-Lon	23240400												1.105	1.053
Lon-JNB	26270400												1.111	1.025
											1.033	1.112	0.994	1.031
Lon-Tok	040		47.1	55.2	46.9	46.7	55.1	58.24	49.70	1.172	1.177	0.948	1.002	1.182
Tok-Lon	050		62.2	74.2	61.1	61.0	62.7	75.99	63.66	1.194	1.215	0.977	1.184	1.217
Lon-Tok	242		53.2	63.0	53.2	53.3	55.9	65.67	55.44	1.185	1.184	0.959	1.127	1.182
Tok-Lon	252		58.9	70.2	59.6	59.1	63.0	74.36	62.41	1.191	1.177	0.944	1.114	1.187
Lon-Tok	202		43.5	51.1	46.2	46.1	53.7	59.22	50.43	1.174	1.106	0.863	0.951	1.108
Tok-Lon	212		46.5	55.2	48.5	48.2	52.9	63.22	53.23	1.188	1.139	0.874	1.044	1.146
											1.166	0.927	1.070	1.170

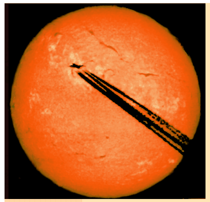
LEGEND
- <5%
- 5% - 10%
- 10% - 20%
- 20% - 30%
- >30%

Different codes provide reasonable agreement with TEPC measurement for periods of low solar activity, but there are always residual errors of up to 30%. These residuals are not systematic – each code sometimes does better on some routes than others.

The differences may arise because the codes:

- **Do not adequately model the Rigidity cutoff – this determines how easily cosmic rays penetrate the Earth's magnetic field**

- **Do not properly model variations in cosmic ray background. Most codes use proxies calculated as monthly averages – influences resulting from solar activity generally have much shorter time scales than this.**



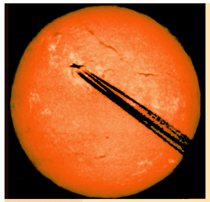
Trying to improve how CARI works

		Original	Daily	Flight
Jo'burg	Mean	0.9207	0.9224	0.9242
	SD	0.0236	0.0221	0.0218
LA	Mean	0.9142	0.9520	0.9493
	SD	0.0560	0.0157	0.0185
Tokyo	Mean	0.9590	0.9799	0.9807
	SD	0.0366	0.0215	0.0211
New York	Mean	0.9803	0.9924	0.9918
	SD	0.0581	0.0376	0.0417
Hong Kong	Mean	0.9308	0.9474	0.9636
	SD	0.0627	0.0437	0.0187
Athens	Mean	1.0642	1.0674	1.0690
	SD	0.0536	0.0574	0.0487
Shanghai	Mean	0.9725	0.9684	0.9673
	SD	0.0205	0.0115	0.0100

<2%
<4%
<6%
<8%
>8%

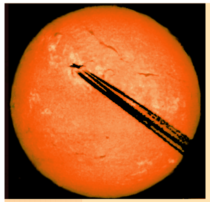
We have also been looking at how to improve the accuracy of CARI, e.g. by calculating the Heliocentric Potential (a proxy to the modulated GCR flux) on a daily and flight-by-flight basis.

There are still problems related to how the codes handle particles from flares.



SOARS

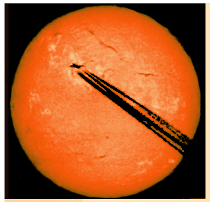
- The Space weather Operational Airline Risk Service (SOARS) is a space weather pilot project jointly funded by ESA. It has the following objectives:
  - Determine how the aviation industry is affected by space weather
  - Propose a service that could help airlines plan their operations
- Involves only space weather effects relevant to aviation
  - Effects of RF Communications
    - Effects of HF and Satellite voice and data communications
    - Effects on Satellite Navigation (e.g. GPS, WAAS)
  - Monitoring radiation exposure of airline crewmembers
  - Monitoring other effects that could be attributed to space weather, e.g. in avionics
- The risks associated with radiation exposure have been studied as part of the project.



Epidemiology and Risks

- Because of the concerns about cancer, several epidemiological studies have been carried out on the effects of cosmic radiation:
  - Early studies involved too small a sample (few hundred)
  - Two detailed studies published in 2003 involved large number of European aircrews over extended periods :
    - Blettner et al. studied a total of 28,000 male cockpit crew from 9 countries, between 1960 and 1997
    - Zeeb et al. studied more than 44,000 cabin crew from 8 countries, from late 1940s to the late 1990s
  - Only cancer that showed any significant increase in occurrence was melanoma *(recreational activities?)*
  - Boice (2000) suggests that the incidence of cancer due to cosmic radiation is too small to be identified by epidemiological studies

- The risks associated with exposure have also been assessed:
  - At the average dose of 3 mSv per annum, the annual average risk of fatal cancer is about 1 in 10,000
  - Aircrew working for 30 years would incur a lifetime risk of developing radiation-induced fatal cancer of 1 in 190 (i.e. ~0.5% risk)
  - The risk incurred would be in addition to the risk in the absence of the occupational exposure. In the general population of the US, about one in four adults (23%) will eventually die of cancer (Landis et al. 1999)

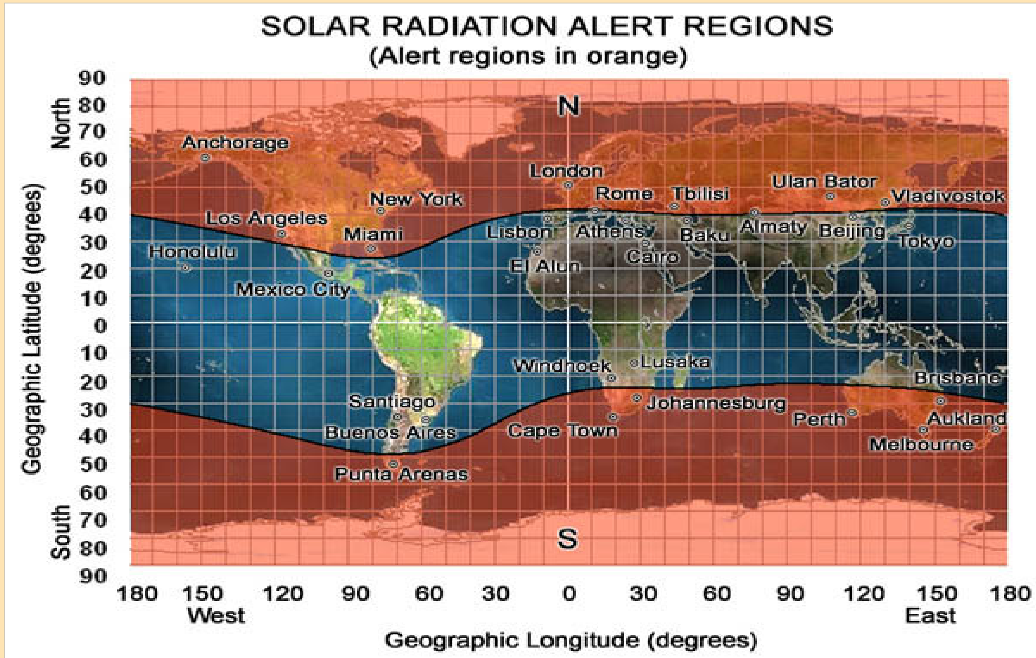


Concerns about Radiation

Radiation Alerts

At time of high solar activity, the US FAA issues Radiation Alerts and instruct it aircraft to fly at lower altitudes – several alerts were issued in Oct-Nov 2003.

Often this is an over-reaction, but aircrew remain concerned about radiation.

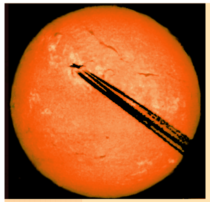


USA TODAY – 28 Mar 2005

Cancer fears limit Hong Kong aircrews' New York trips

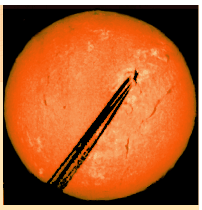
HONG KONG (AFP) — Airline Cathay Pacific has limited aircrews' flights on the non-stop Hong Kong-New York route after it was found the journey could increase the likelihood of cancer, a report said Sunday.

Staff of the British-owned, Hong Kong-based airline say they have been limited to just two of the ultra long-haul flights per month since it was found the route exposed passengers and crew to high levels of cosmic radiation when they flew over the North Pole.



Summary

- Exposure to cosmic radiation has become an issue for the European airlines because of recent legislation
- Airlines are required to monitor crew exposure
  - For a typical mix of flights this is not a problem, but it could be for crews dedicated to long distance, high latitude routes
- Epidemiological studies suggest that the increased incidence of cancer is difficult to measure and the risks seem relatively low (although comparison with exposure in other workplaces is not simple)
  - New planes fly higher and the problems will increase
  - Space tourism could add a new dimension to the issue
- UCL looking at developing TEPC that can be used on aircraft as a standard piece of avionics
  - Remove the uncertainty in modelling for high dose cases



Space weather Operational Airline Risks Service (SOARS)